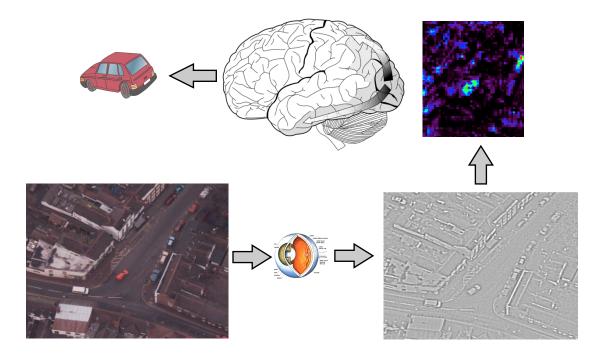# Visual Cortex on a Chip
Large-scale, real-time functional models of mammalian visual cortex on a GPGPU

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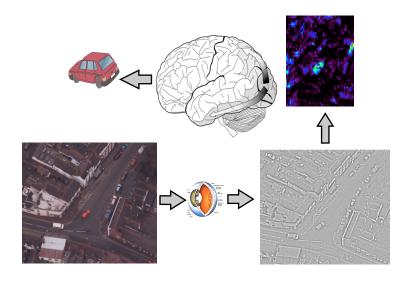GPU Technology Conference 2010, San Jose CA

http://synthetic-cognition.lanl.gov

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Large-scale, real-time functional models of mammalian visual cortex on a GPGPU

Concept

Full-scale simulation of human vision

is a petascale computing challenge,

and is now feasible with Roadrunner.

Project Goals

Science Goal: Explore new neuroscience-inspired artificial neural networks using unique petascale computing resources at LANL (Roadrunner) for robust, human-like feature and object extraction from video and imagery datasets
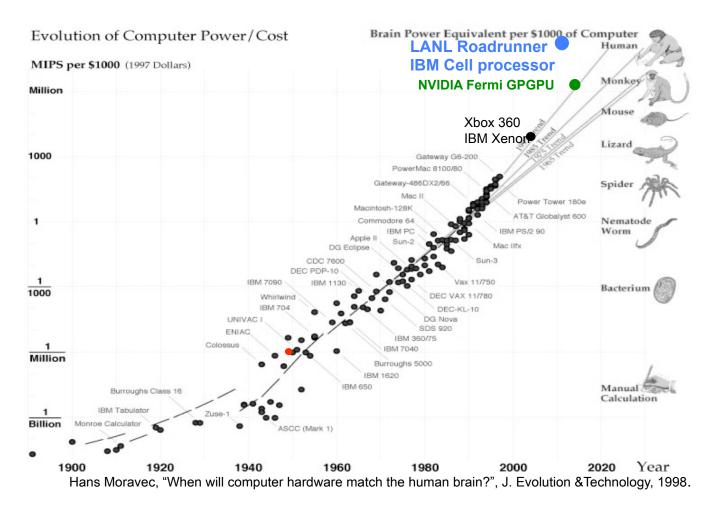
Performance Goal: Full-scale, real-time model of human visual cortex ~ 1080p HD video at >10 fps.

Technical Approach

1. Full-scale model of visual cortex using:
   synaptic plasticity / machine learning,
   models of color processing,
   feed-back/lateral connectivity,
   and spiking dynamical neurons.

2. Unique petaflop (Roadrunner/Cell) and multi-teraflop single-rack GPGPU-accelerated high performance computing systems.

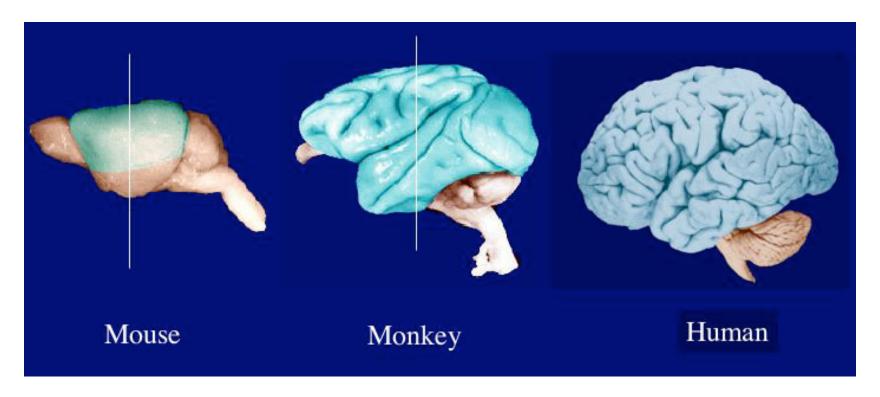3. A $6M R&D investment by DOE/LANL LDRD-DR, NSF, and DARPA.

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Evolution of Computer Power/Cost

Brain Power Equivalent per $1000 of Computer

MIPS per $1000 (1997 Dollars)

LANL Roadrunner
IBM Cell processor
NVIDIA Fermi GPGPU

Xbox 360
IBM Xenon

Human
Monkey
Mouse
Lizard
Spider
Nematode Worm
Bacterium
Manual Calculation

Gateway G6-200
PowerMac 8100/80
Gateway-486DX2/66
Mac II
Macintosh-128K
Commodore 64
IBM PC
Apple II
DG Eclipse
Sun-2
CDC 7600
DEC PDP-10
IBM 7090
IBM 1130
Whirlwind
IBM 704
UNIVAC I
ENIAC
Colossus
Power Tower 180e
AT&T Globalyst 600
IBM PS/2 90
Mac IIfx
Sun-3
Vax 11/750
DEC VAX 11/780
DEC-KL-10
DG Nova
SDS 920
IBM 360/75
IBM 7040
Burroughs 5000
IBM 1620
IBM 650
Burroughs Class 16
IBM Tabulator
Zuse-1
Monroe Calculator
ASCC (Mark 1)

1995 Trend
1985 Trend
1975 Trend
1965 Trend

Million
1000
1
1/1000
1/Million
1/Billion

1900 1920 1940 1960 1980 2000 2020 Year

Hans Moravec, "When will computer hardware match the human brain?", J. Evolution &Technology, 1998.

Computing hardware for large-scale simulations of human cortex exists now:
With petascale supercomputers, such as LANL's Roadrunner, large-scale simulations can be run at real-time on full-scale visual datasets (~months of HD video). GPGPU enables experiments at small-mammal scale using machines costing a few k$.

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Mouse   Monkey   Human

- Mouse cortex: 4,000,000 neurons
- Cat cortex: 300,000,000 neurons
- Monkey cortex: 6,000,000,000 neurons
- Human cortex: 11,000,000,000 neurons (~100G neurons whole brain)
- ~10,000 synapses (connections) per neuron
- 130 types of neurons in human brain

NNSA

Artificial Neural Networks

Spiking Dynamics

Existing Models
Grossberg/Carpenter ART
Poggio MIT models
LeCun Deep networks
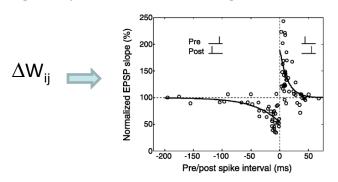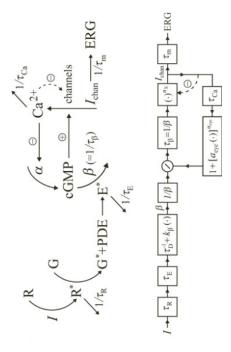
Biochemical Models
Blue Brain (EPFL)

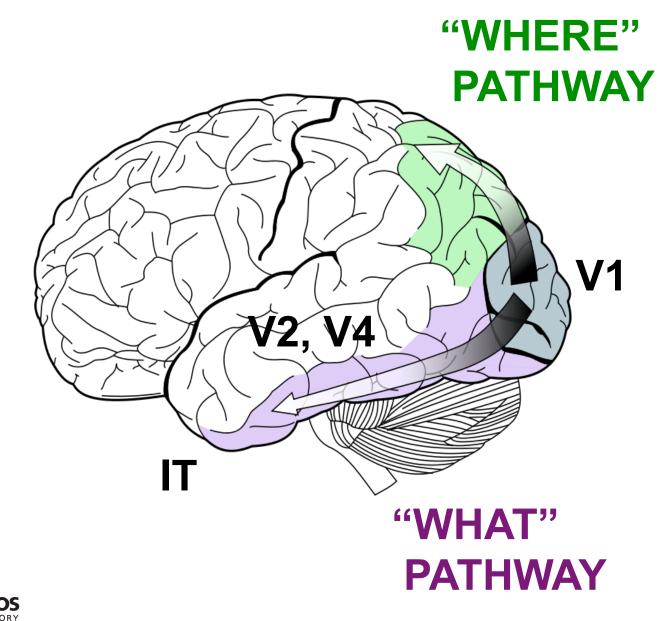ΔW_{ij}
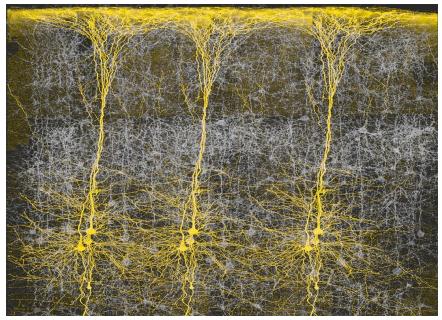
Feedback Loops

ΔW_{ij}

Synaptic Plasticity

ΔW_{ij}

Next generation Artificial Neural Networks: Goal is functional models of visual cortex based on recent work in neuroscience.

NNSA

"WHERE" PATHWAY
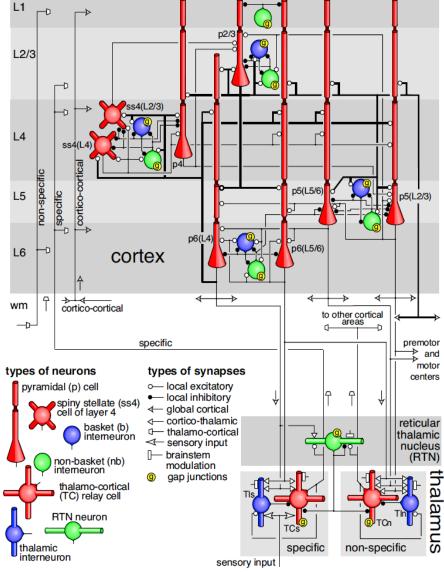
V1

V2, V4

IT

"WHAT" PATHWAY

E.M. Izhikevich & G.M. Edelman, (2008)
Proc. National Acad. Sci. 105:3593-3598
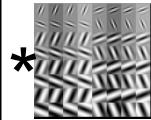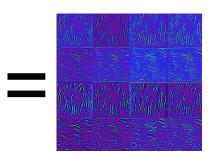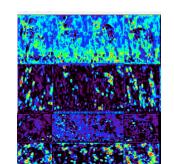Large-Scale Model of Mammalian
Thalamocortical Systems,

Processing in Retina
Local contrast equalization, for each patch set mean to zero and local Euclidean norm to 1.

Processing in S-cells
Radial Basis Functions with standard oriented Gabor neuron weight vectors [3-5].

$$s_{RBF}(r, w_G) = \exp\left(-\frac{1}{2}\beta(r - w_G)^2\right)$$

$$w_G = w(\theta, \gamma, \sigma, \lambda, \phi) = \exp\left(-\frac{1}{2\sigma}(x_\theta^2 + \gamma y_\theta^2)\right)\cos\left(\frac{2\pi x_\theta}{\lambda} + \phi\right)$$

Processing in C-cells
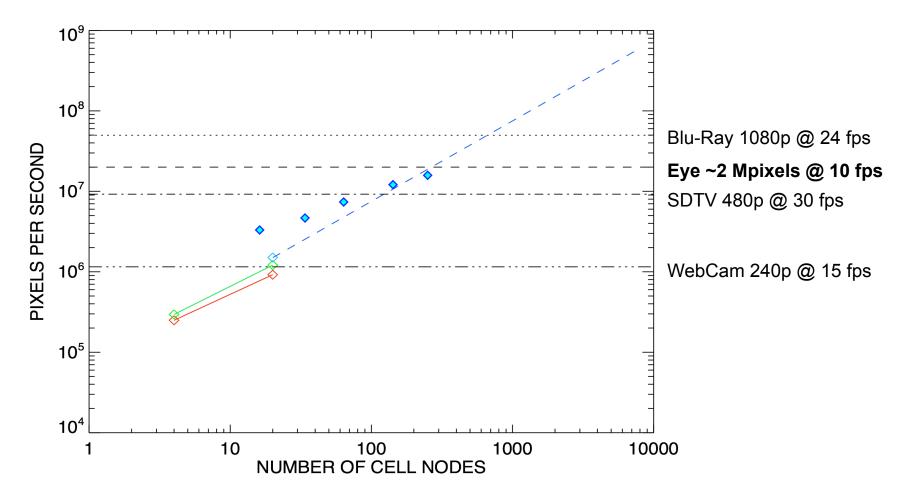MAX Function over S-cell receptive fields.

$$c_{MAX}(s) = \max_{i \in I_j}\left(\{s_i\}\right)$$
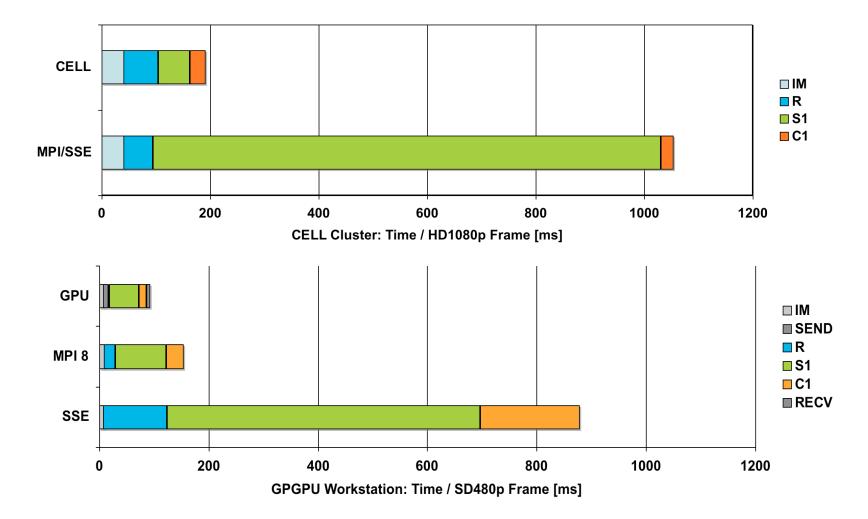
Standard model of visual cortex
LANL's PANN code is a high performance implementation in
C++/C and Python of a Neocognitron model [Fukushima; Poggio et al.].

LANL supercomputing assets have allowed us to reach full-scale processing at real-time video rates. Codes can also run on GPU or conventional multi-core machines.

CELL Cluster: Time / HD1080p Frame [ms]

Legend: IM, R, S1, C1

GPGPU Workstation: Time / SD480p Frame [ms]

Legend: IM, SEND, R, S1, C1, RECV

LANL codes exploit conventional multi-core/ multi-cpu clusters, vector processing on cpu cores (SSE), and "cluster on a chip" hardware (CELL, GPGPU).
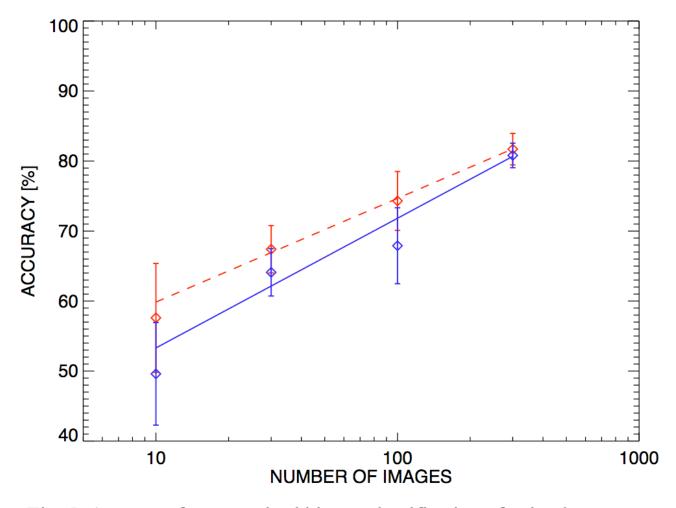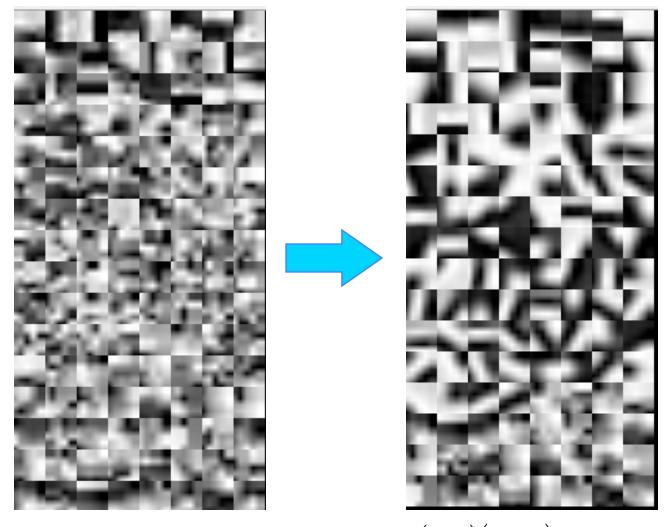
Fig. 5. Accuracy for supervised binary-classification of animal versus no animal images as a function of training set size for V1-V2 model using imprinting (red dashed line) or Hebbian learning (blue solid line). Lines show fit of a simple model, $A = a + b \ln(N_T)$, with 1 standard deviation error bars.

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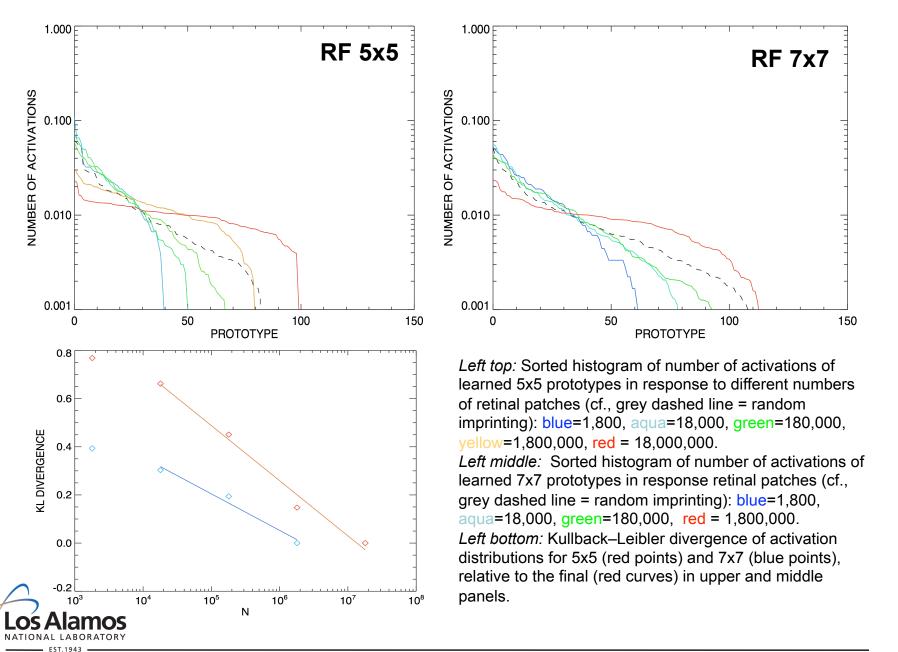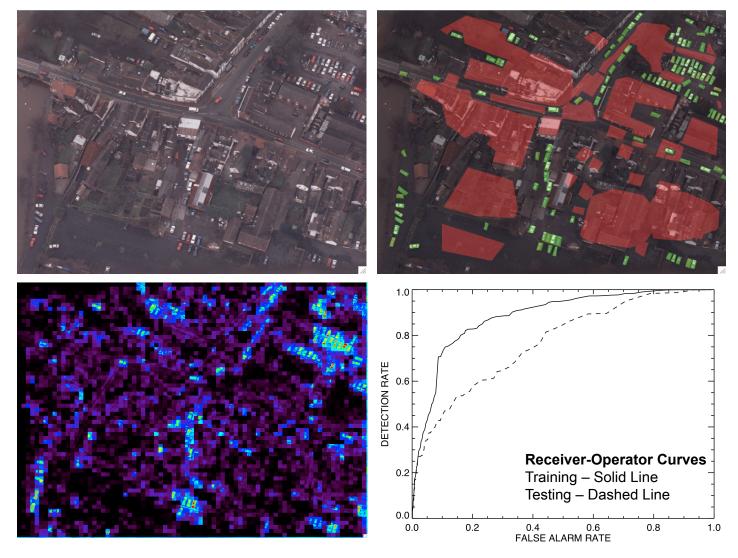NATIONAL LABORATORY
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Hebb–Oha learning rule: $\Delta w = \lambda\, y(r, w)(r - w)$
Visual cortex models are self-organizing using neuroscience-inspired learning rules.

Left top: Sorted histogram of number of activations of learned 5x5 prototypes in response to different numbers of retinal patches (cf., grey dashed line = random imprinting): blue=1,800, aqua=18,000, green=180,000, yellow=1,800,000, red = 18,000,000.

Left middle: Sorted histogram of number of activations of learned 7x7 prototypes in response retinal patches (cf., grey dashed line = random imprinting): blue=1,800, aqua=18,000, green=180,000, red = 1,800,000.

Left bottom: Kullback–Leibler divergence of activation distributions for 5x5 (red points) and 7x7 (blue points), relative to the final (red curves) in upper and middle panels.

Receiver-Operator Curves
Training – Solid Line
Testing – Dashed Line

Visual cortex models can be applied to non-traditional computer vision tasks, such as vehicle identification in satellite/aerial imagery and video.

Brumby et al., IEEE Proc. AIPR 2009.
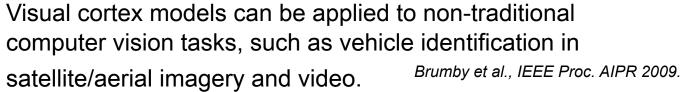
Vehicle Tracking in UAV-like Video

We have preliminary results using a learned model of primary visual cortex on public-release UAV-like imagery of vehicle detection and tracking scenarios provided by the DARPA/DSO Neovision2 program. We are currently working to explore and optimize the object-recognition capabilities of visual cortex models under different conditions of learning rule, initial network topology, and training set size. Initial results suggest that visual cortex models such as PANN are a promising approach to this hard visual pattern recognition problem. GPGPU acceleration may be the key enabling technology for this type of application, as exploiting the GPGPU enables a better than order-of-magnitude speed-up of execution of the model on workstations, enabling learning of better models and faster execution of the final model.
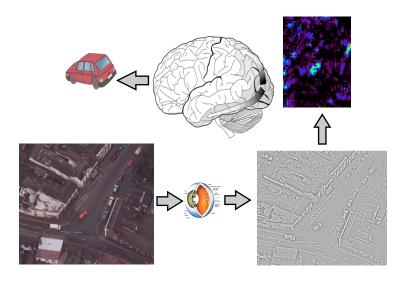
TRAINING FRAME

TEST FRAME

TEST FRAME : RESULT

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